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TRANSONIC WIND-TUNNEL TESTS OF A LIFTING PARACHUTE MODEL

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16. Abstract

Wind-tunnel tests have been made in the Langley transonic dynamics tunnel on a 0.25-scale model of Sandia Laboratories' 3.96-meter (13-foot), slanted ribbon design, lifting parachute. The lifting parachute is the first stage of a proposed two-stage payload delivery system. The lifting parachute model was attached to a forebody representing the payload. The forebody was designed and installed in the test section in a manner which allowed rotational freedom about the pitch and yaw axes. Values of parachute axial force coefficient, rolling moment coefficient, and payload trim angles in pitch and yaw are presented through the transonic speed range. Data are presented for the parachute in both the reefed and full open conditions. Time history records of lifting parachute deployment and disreefing tests are included.

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TRANSONIC WIND-TUNNEL TESTS OF A

LIFTING PARACHUTE MODEL

Jerome T. Foughner, Jr., James F. Reed,* and Eleanor C. Wynne

SUMMARY

Wind-tunnel tests have been made in the Langley transonic dynamics tunnel on a 0.25-scale model of Sandia Laboratories' 3.96-meter (13-foot), slanted ribbon design, lifting parachute. The lifting parachute is the first stage of a proposed two-stage payload delivery system. The lifting parachute model was attached to a forebody representing the payload. The forebody was designed and installed in the test section in a manner which allowed rotational freedom about the pitch and yaw axes. Values of parachute axial force coefficient, rolling moment coefficient, and payload trim angles in pitch and yaw are presented through the transonic speed range. Data are presented for the parachute in both the reefed and full open conditions. Time history records of lifting parachute deployment and disreefing tests are included.

INTRODUCTION

A two-stage parachute system is currently under development at the Energy Research and Development Administration (ERDA) Sandia Laboratories. This system is for high-speed, low-altitude payload delivery and is illustrated in figure 1. The first stage is a lifting parachute which raises the payload to an altitude higher than the release altitude where a conventional parachute (second stage) is deployed for the descent to ground. As indicated in reference 1, the use of two parachutes in a staged system can decrease the impact energy of a payload to one-tenth that of a conventional single parachute system and also can insure a near-vertical impact angle. Low subsonic speed wind-tunnel tests of scale models, summarized in reference 2, were used extensively to evaluate potential lifting parachute designs and to optimize and evaluate the characteristics of the selected slanted ribbon design. Development of the first stage lifting parachute is continuing with a program of wind-tunnel tests and full-scale tests to measure aerodynamic characteristics and to further optimize the lifting parachute design.

In support of an ERDA request to determine transonic aerodynamic performance characteristics of Sandia's 3.96-meter (13-foot) slanted-ribbon lifting parachute, some wind-tunnel tests were conducted in the Langley transonic dynamics tunnel by using a 0.25-scale model. The primary purpose of this study was to measure parachute axial force, trim angle and roll torque for

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the full-open parachute. Secondary purposes included similar measurements for the parachute in a reefed condition and the measurement of the parachute's opening characteristics when it was deployed from a payload model. Tests were conducted over a dynamic pressure range from 1.20 kPa (25 lbf/ft^2) to 4 79 kPa (100 lbf/ft^2) at Mach numbers from 0.25 to 1.14. This paper presents the results from these tests.

SYMBOLS

The principal measurements and calculations presented in this paper are made in U. S. Customary Units and were converted to the International System of Units (SI) for presentation. In some cases both SI and Customary Units are used. When this is done, the SI units are stated first, and Customary Units afterwards in parentheses. When no units are stated, the ones used are those given in the symbol list.

C_A	axial force coefficient, F_A/qS
C_ℓ	rolling moment coefficient, ℓ_m/qSD_C
D_C	parachute constructed diameter, .9906 meter (3.25 ft)
F_A	axial force
L_R	length of reefing line
ℓ_m	rolling moment
M	freestream Mach number
q	freestream dynamic pressure
S	cross sectional area, 0.771 meter^2 (8.296 ft^2)
α	payload model pitch angle, positive nose up
β	payload model yaw angle, positive nose left
ρ	fluid density

APPARATUS AND TECHNIQUE

Wind Tunnel

The tests were conducted in the Langley transonic dynamics tunnel which has a 4.9-meter square (16-foot) test section with cropped corners and is a return-flow, variable-pressure, slotted-throat wind tunnel. The cross-sectional area of the test section is 23 meters^2 (248 ft^2). The tunnel is capable of operation at stagnation pressures from 0.1 atmosphere to atmospheric pressure and at Mach numbers up to 1.2. Mach number and dynamic pressure can be varied independently with either air or Freon used as a test medium; however, these tests were conducted using air as the test medium.

Models

A photograph of the lifting parachute mounted in the wind tunnel is presented in figure 2. Some parachute model construction details are shown in figure 3.

Parachute lift was accomplished by asymmetry in construction. Specifically, lift was developed by using a liner at the top and slanted ribbons at the bottom to modify the pressure distribution in the upper and lower regions of the canopy. The slanted ribbons provided additional geometric porosity at the bottom. The total geometric porosity for this design is approximately 10 percent. For these tests suspension line lengths of 1.08 D_c were used. The parachute was attached to the outer edge of an adapter ring at the rear of the payload model as shown in figure 2. This ring physically restrained the parachute in roll. Three "identical" parachute models were used during the wind tunnel tests.

The payload model consisted of a body of revolution 11.43 cm (4.5 inches) in diameter and 92.08 cm (36.25 inches) in length. The body had an ogive nose and four stabilizing fins. The payload model was mounted on a shaft and was supported in the wind tunnel, 0.61 m (2 feet) below the tunnel centerline, on an eight-cable mount system as shown in figure 2. Ball bearings were located at the ends of the shaft through the payload model to allow pitch rotation of +15 degrees to −40 degrees. A second pair of bearings inside the payload model permitted ±20 degrees of yaw freedom.

Instrumentation and Data Reduction

Parachute axial force and roll moment were measured by using strain gage beams located inside the payload model. The axial force and roll moment balance assembly is shown in figure 4. Payload pitch and yaw trim angles were determined by using potentiometers. Signal outputs and IRIG-B time code were recorded on analog tape with a tape speed of 38.1 cm per second (15 inches per second) and a center frequency of 27.0 KHz.

For data analysis the analog tape data were converted to digital data at 1000 samples per second. A record length of 3 seconds was used in calculating the mean values of each data channel. By using the recorded amplifier zero levels and the calculated mean values of the sensor output signals, the steady state forces and trim angles were determined. The steady state forces were then converted to coefficient form by using the formula, and reference length and area shown in the symbol list.

Test Conditions and Procedure

Steady state force, moment, and payload trim angle were obtained on a fully open parachute from Mach number 0.25 to 0.95 and on a reefed parachute (L_R/D_C = 0.41) from Mach number 0.80 to 1.11. Three deployment tests at Mach numbers 0.25, 0.60 and 1.14 were made. Two disreefing tests, from 35-percent and 41-percent reefed to full open, were also made at Mach numbers 0.52 and 0.92, respectively.

For the force and trim angle tests the parachutes were attached to the payload model in a deployed state. When applicable, mid-gore skirt reefing was used to constrict the opening to the required reefing ratio.

For the deployment tests the lifting parachute was packed in a nylon deployment bag which trailed behind the payload model. A 0.61-meter (2-ft) diameter ribbon drogue parachute of 18-percent porosity was attached to the deployment bag and allowed to operate in the wake of the bag and payload model. The drogue parachute was restrained from pulling out the lifting parachute during tunnel start-up and was tied to the tunnel wall by a light line to prevent it from going down the tunnel when the lifting parachute was deployed. When the tunnel was stabilized at the desired test conditions, the drogue was released allowing the lifting parachute to deploy.

For the disreefing tests the parachutes were attached to the payload model in a deployed state in their reefed condition. When the desired test conditions were reached, the parachute reefing line was cut allowing the parachute to disreef to full open.

RESULTS AND DISCUSSION

Basic Performance

The basic lifting parachute performance data through the transonic range is presented in figure 5. The variations with Mach number of the parachute axial force coefficient and rolling moment coefficient together with the payload model pitch and yaw angles are shown. The parachute lift to drag ratio may be estimated by taking the tangent of the payload pitch trim angle α. Results are presented both for the full open parachute and a reefed parachute (L_R/D_C = 0.41) at dynamic pressure levels of 1.20 kPa (25 lbf/ft^2) to 4.79 kPa (100 lbf/ft^2 Dynamic pressure levels are constant

at 4.79 kPa (100 lbf/ft^2) above a Mach number of 0.6.

The variation of axial force coefficient with Mach number is shown in figure 5a. For the full open parachute the axial force coefficient is nearly constant at 0.72 up to a Mach number of 0.6. This value is in agreement with the subsonic axial force coefficient of 0.70 obtained in reference 2. The axial force coefficient then increases to approximately 0.86 at a Mach number of 0.85 and decreases to 0.78 at the maximum test Mach number of 0.95. The reefed parachute axial force coefficient is constant at approximately 0.28 throughout the Mach number range.

The variation of payload model pitch trim angle with Mach number is shown in figure 5b. In general, the payload trim angle for both the full-open and reefed (L_R/D_C = .41) parachutes gradually decreased in magnitude with increasing Mach number. The payload pitch angles ranged from a minimum of -25° to a maximum of -27.5° for the full-open parachute, and ranged from a minimum or -2.5° to a maximum of -6.0° for the reefed parachute. The pitch trim angle of -25.8 degrees measured at Mach 0.25 for the full-open case agrees well with the value of -25.0 degrees reported in reference 2 for a similar configuration at corresponding test conditions.

The variations of the full-open parachute rolling moment coefficient and the payload model yaw angle with Mach number are shown in figures 5c and 5d, respectively. Due to unexpected dynamic oscillations in roll and yaw obtained for the reefed configuration, the rolling moment coefficient and the static yaw angle could not be determined with confidence. Therefore, no rolling moment and yaw angle data are presented for the reefed parachute. A rolling moment coefficient on the order of -.0002 was measured throughout the Mach number range. The payload model yaw angle (fig. 5d) has an average value of -2.6 degrees over the Mach number range.

Deployment

Parachute axial force and rolling moment, and payload pitch and yaw angle time histories are shown in figures 6, 7, and 8. The data in figure 6 were obtained during a deployment to full open at M = 0.25 and q = 4.31 kPa (90 lbf/ft^2). The data in figure 7 were obtained during a deployment to full open at M = 0.60 and q = 4.84 kPa (101 lbf/ft^2). The data in figure 8 were obtained during a deployment to a reefed condition, L_R/D_C = 0.41, at M = 1.14 and q = 4.79 kPa (100 lbf/ft^2).

The deployment at M = 0.25 (fig. 6) was successfully accomplished. A transient payload pitch oscillation did occur, but this oscillation was highly damped, and the amplitude decayed rapidly. Some high frequency, about 110 Hz, rolling moment oscillations were present, but the level was within the $\pm$3 meter-newton (2.25 ft-lbf) maximum allowable moment range of the model balance.

At M = 0.60 large amplitude oscillations occurred after the deployment for all of the time histories shown in figure 7. Two and one-half seconds

after deployment the parachute tore loose from the payload. The fact that one of the 24 suspension lines broke upon deployment may have contributed to the ultimate parachute failure.

After the deployment at $M = 1.14$ (fig. 8) diverging-amplitude sinusoidal oscillations occurred in both rolling moment and payload yaw angle. The frequency of these oscillations was about 3.4 Hz. The amplitudes exceeded the ± 3 meter-newton (2.25 ft-lbf) rolling moment limit and the payload yaw angle limit of $\pm 20^{\circ}$.

Disreefing

Parachute axial force, rolling moment, and payload pitch and yaw angle time histories associated with disreefing are shown in figures 9 and 10. The data in figure 9 were obtained by disreefing from $L_R/D_C = .41$ to full open at $M = 0.52$ and $q = 1.48$ kPa (31 lbf/ft^2). The data in figure 10 were obtained by disreefing from $L_R/D_C = .35$ to full open at $M = 0.92$ and $q = 3.59$ kPa (75 lbf/ft^2). Both sets of data show that prior to disreefing the payload was experiencing a large amplitude sinusoidal yawing oscillation which was induced by a parachute rolling oscillation. Although the payload amplitude was about the same in both cases, the parachute rolling moment was considerably larger at $M = 0.92$. Upon disreefing at $M = .52$ (fig. 9), roll-yaw instability occurred. Seven seconds after disreefing (not shown in figure 9), the amplitude became so large that the parachute wrapped around one of the payload support cables. Upon disreefing at $M = .92$ (fig. 10), there was a decrease in amplitude of the payload yaw and parachute roll oscillations which lasted for about 26 seconds. At this time, although the wind-tunnel flow conditions were being held constant, a large amplitude roll-yaw instability occurred and was of such magnitude that the payload was damaged.

CONCLUDING REMARKS

A 0.25-scale model of the Sandia Laboratories' 3.96-meter (13-ft) slanted ribbon lifting parachute was tested in the Langley transonic dynamics tunnel. The parachute was attached to a payload model which was free to pitch and yaw. Full open and reefed parachute characteristics were determined. The axial force coefficient of the full open parachute was constant at 0.72 up to a Mach number of 0.6, increased to approximately 0.86 at a Mach number of 0.85, and decreased to 0.78 at a Mach number of 0.95. The axial force coefficient for the reefed parachute was constant at 0.28 over the Mach number range from 0.25 to 1.11.

In general, a gradual decrease in pitch trim angle occurred as Mach number was increased. The pitch trim angle was -27.5 degrees at 0.6 Mach number and changed to -25.0 degrees at a Mach number of 0.95. The reefed parachute had a pitch trim angle of -4.5 degrees at 0.8 Mach number and changed to -2.5 degrees at a Mach number of 1.11.

A rolling moment coefficient on the order of -.0002 was measured throughout the Mach number range on the full open parachute. Yaw angle for the full open parachute averaged -2.6 degrees over the Mach number range. Due to unexpected dynamic oscillations in roll and yaw obtained for the reefed configuration, the rolling moment coefficient and the static yaw angle could not be determined.

Time histories of parachute axial force and rolling moment, and payload pitch and yaw angles have been presented for three parachute deployments and two disreefings. The parachute performance was satisfactory for a deployment at Mach number 0.25, but for the other cases at transonic speeds, dynamic instabilities occurred.

REFERENCES

1. Rychnovsky, Raymond E.: A Lifting Parachute for Very Low-Altitude, Very High-Speed Deliveries. AIAA Paper No. 75-1389, November 1975.

2. Rychnovsky, Raymond E. and Everett, R. N.: Wind Tunnel Tests to Evaluate a Lifting Transonic Parachute. AIAA Paper No. 75-1365, November 1975.

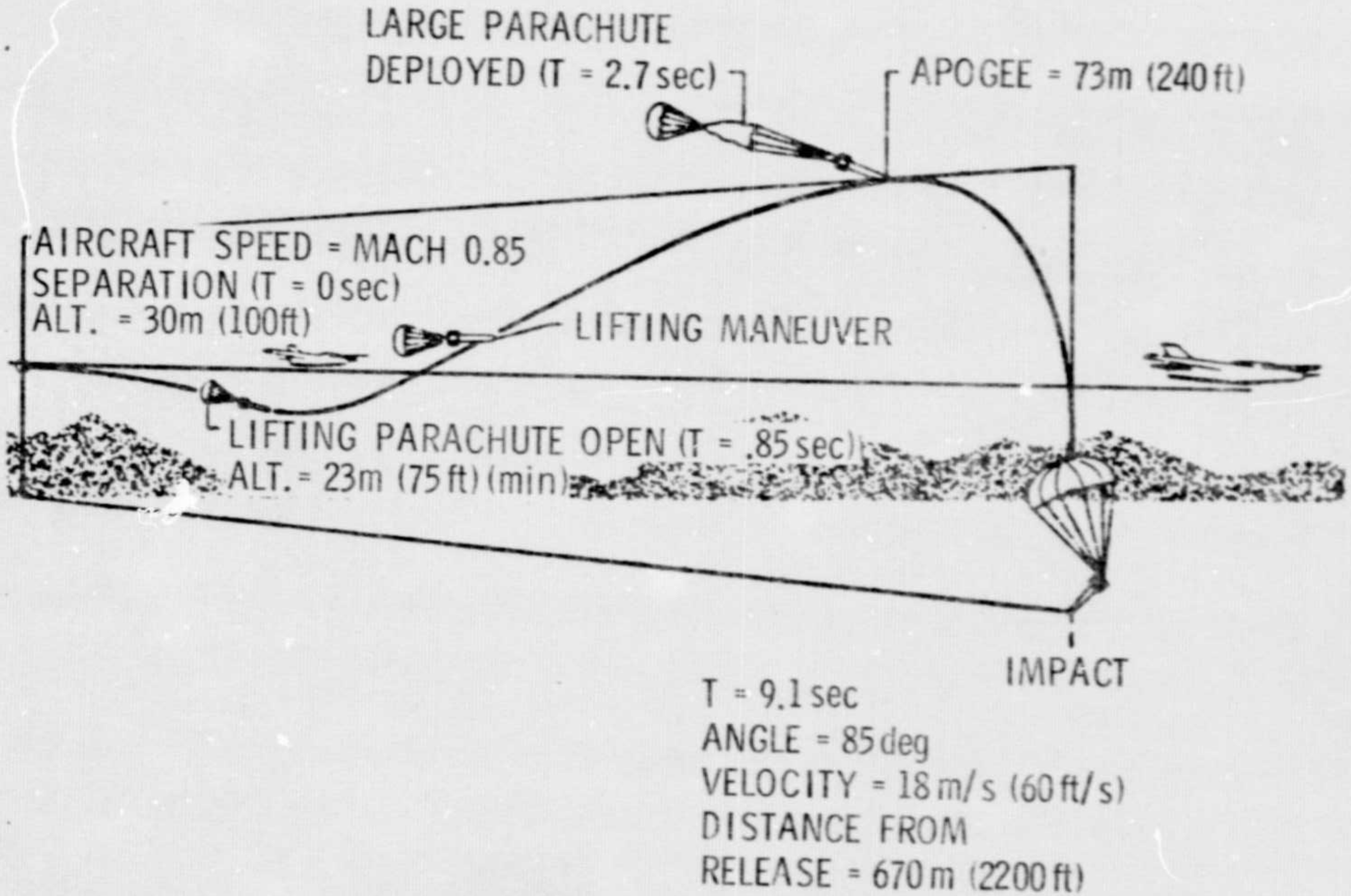

Figure 1.- Two stage payload delivery system (from ref. 1).

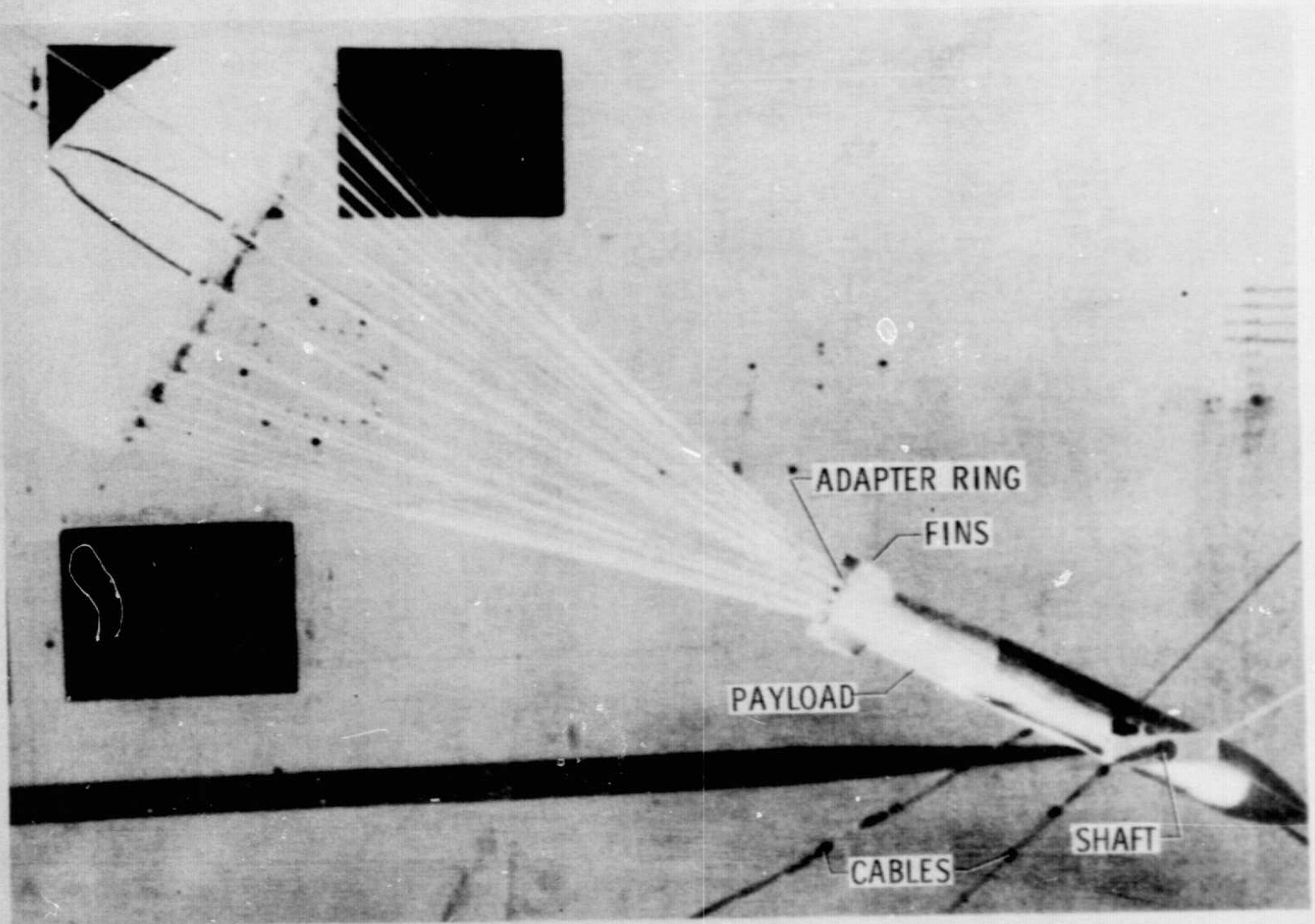

Figure 2.- Payload with lifting parachute on cable support system.

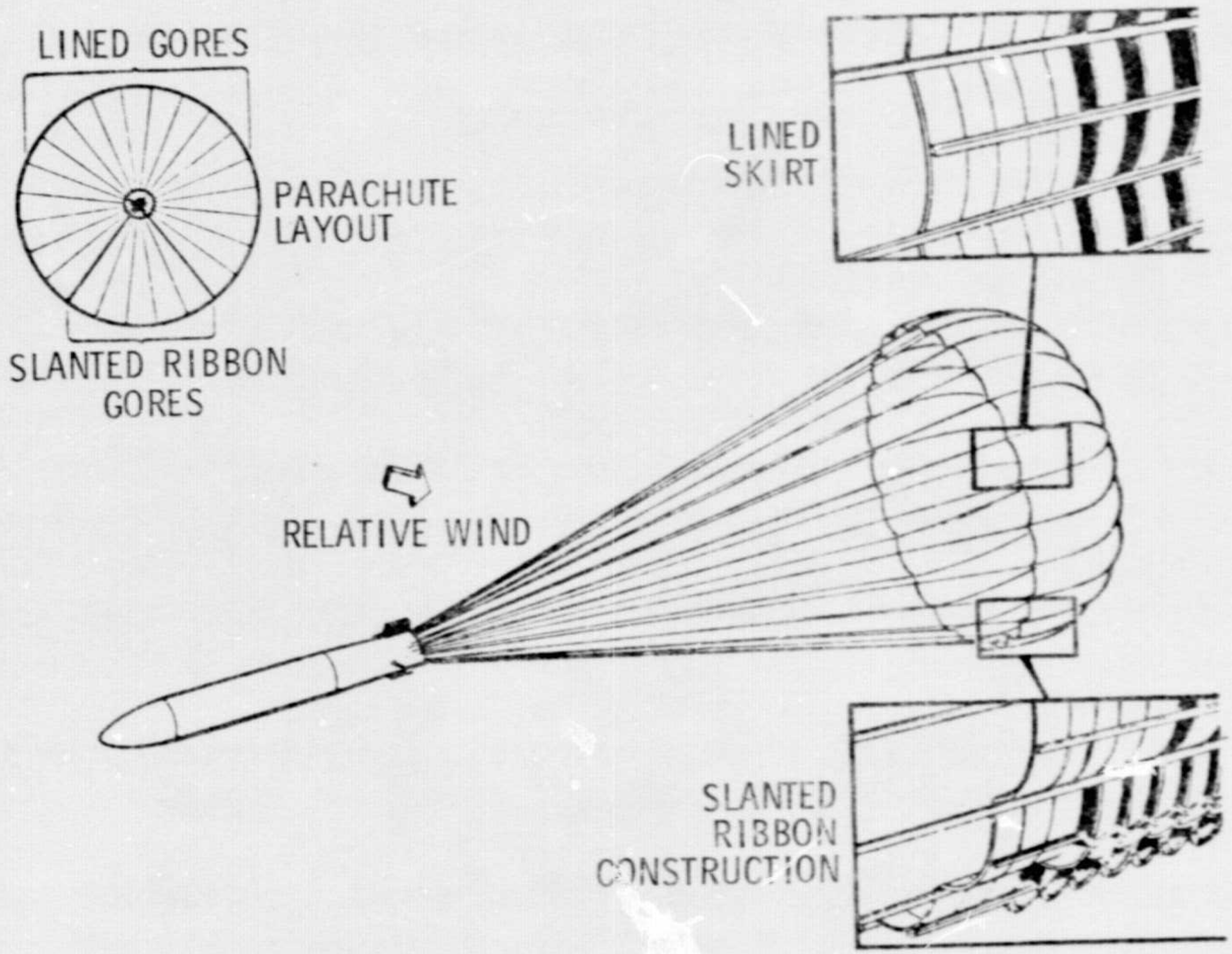

Figure 3.- Slanted ribbon lifting parachute (from ref. 2).

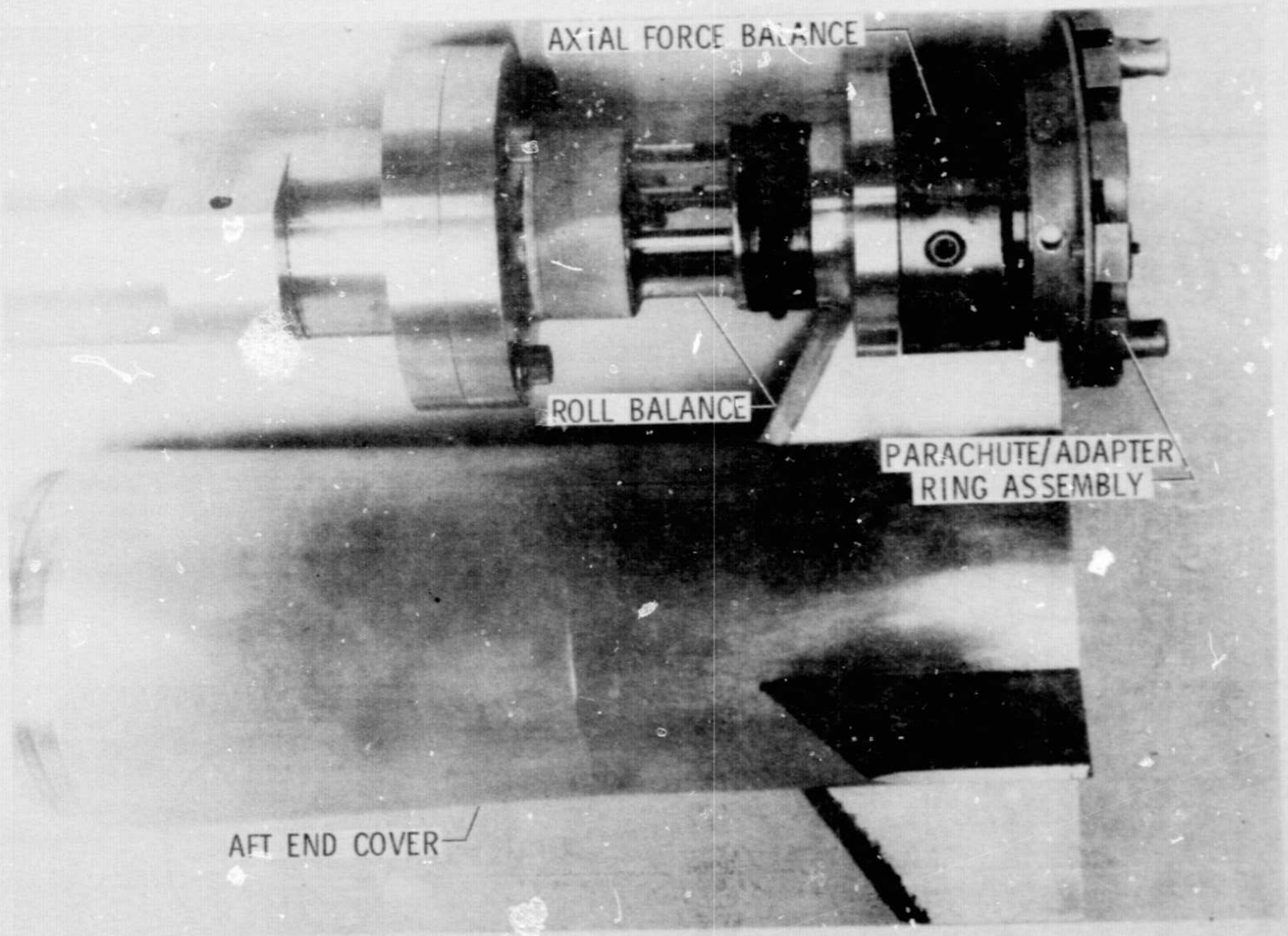

Figure 4.- Payload aft end cover with axial force and roll moment balances.

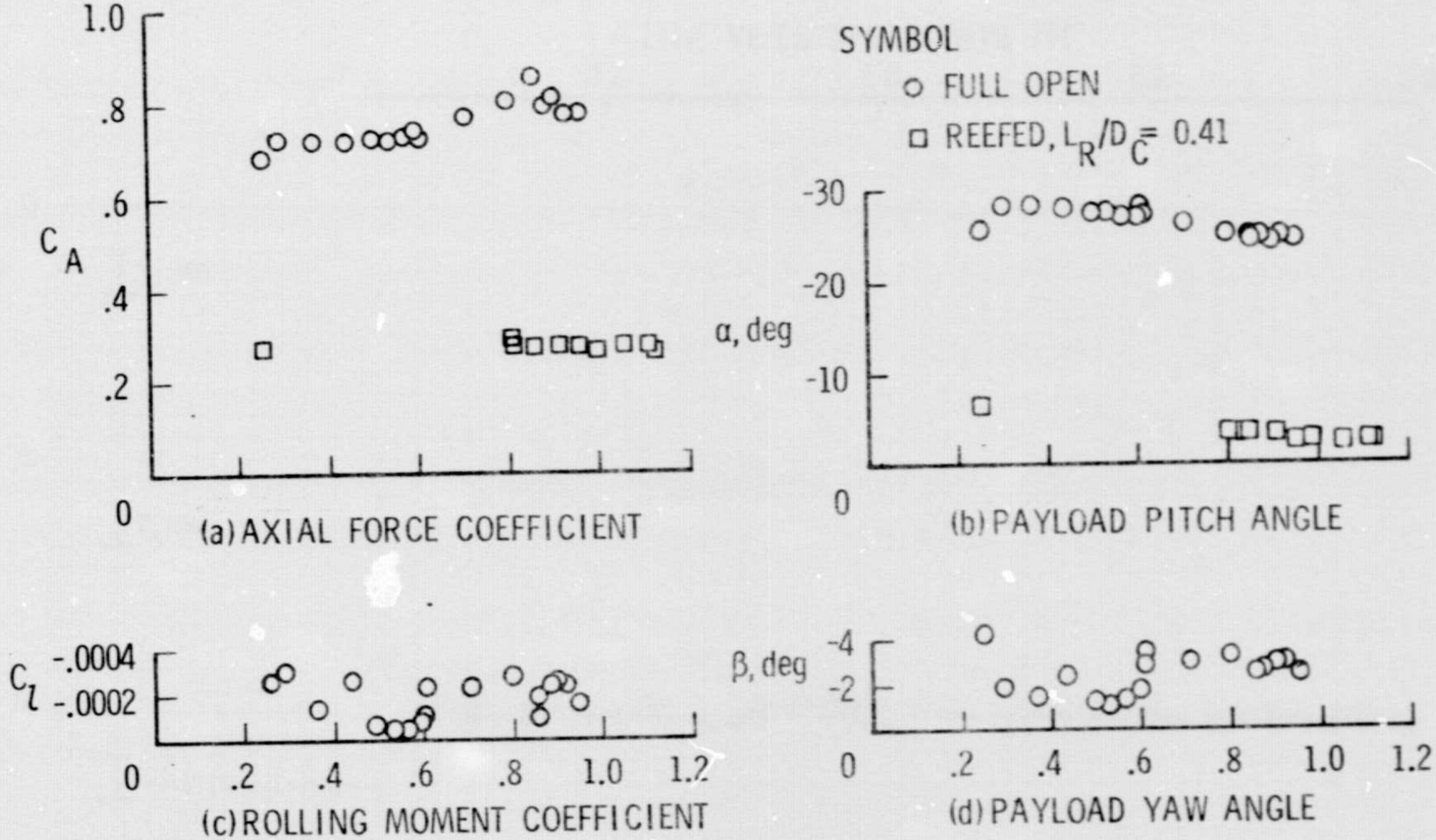

Figure 5.- Aerodynamic characteristics for slanted ribbon lifting parachute-payload system through the transonic range.

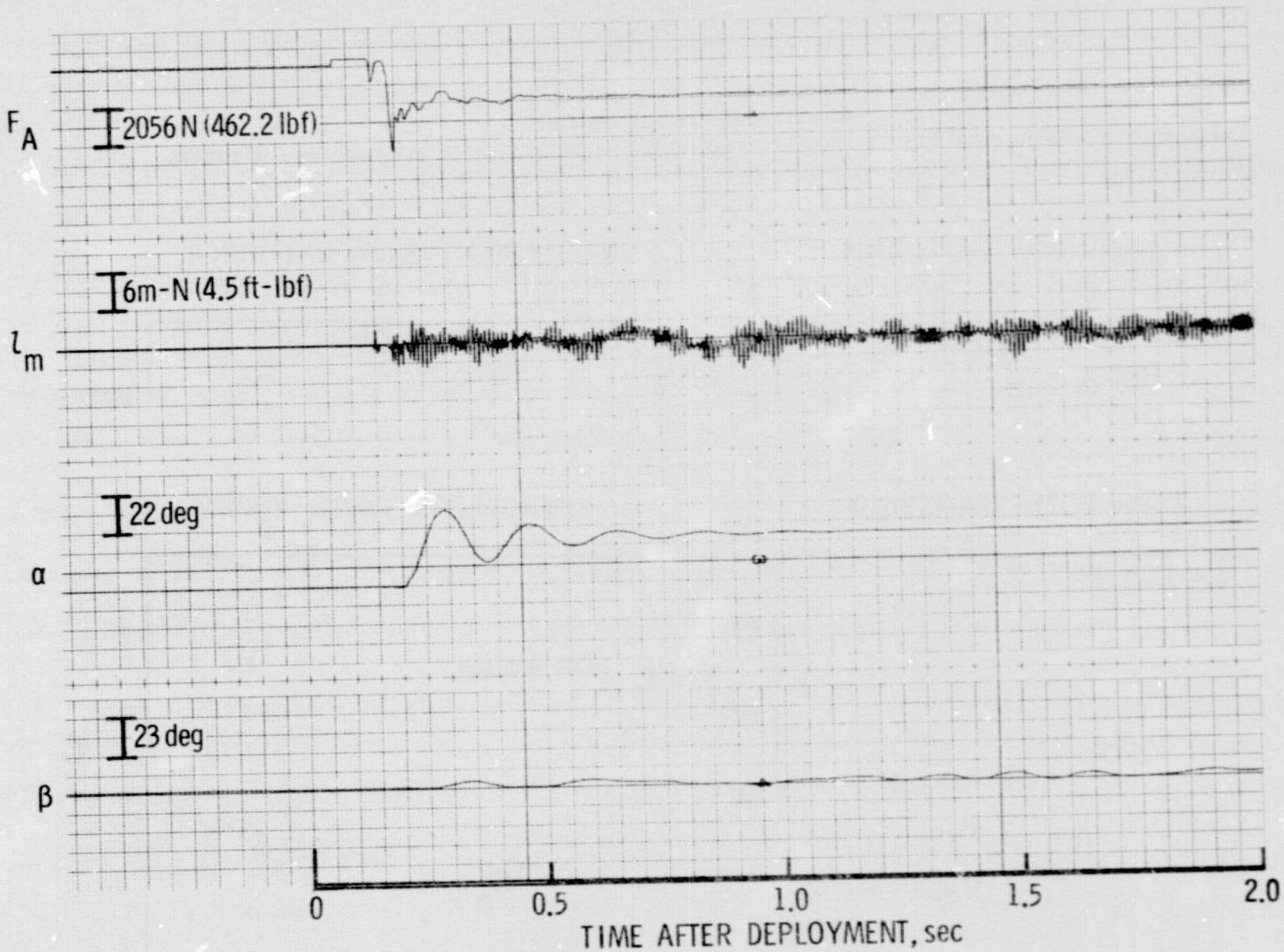

Figure 6.- Time histories for deployment to a parachute full open condition. M = 0.25, q = 4.31 kPa (90 lbf/ft^2), ρ = 1.199kg/m^3.

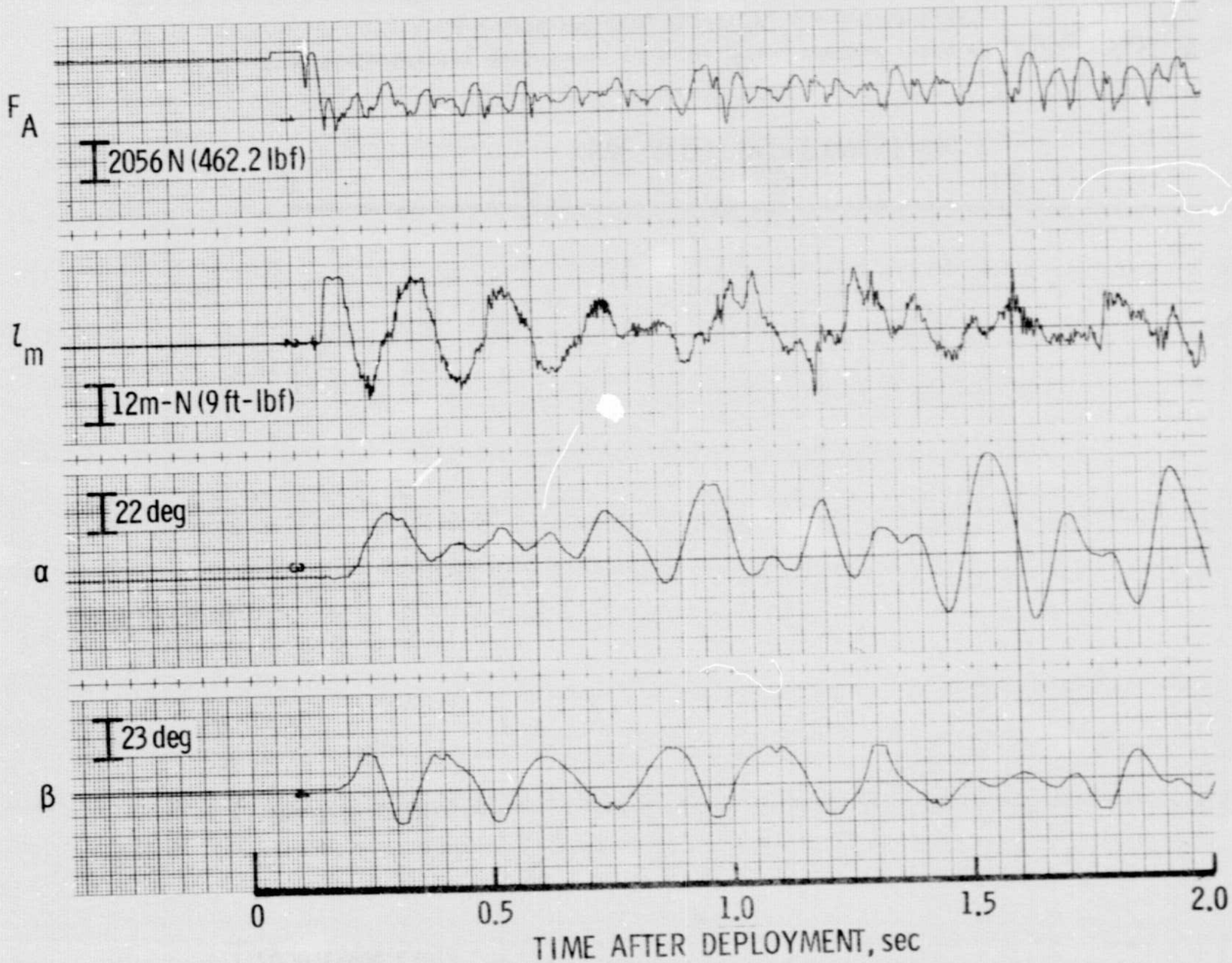

Figure 7.- Time histories for deployment to a parachute full open condition. $M = 0.60$, $q = 4.84$ kPa (101 lbf/ft^2), $\rho = 0.236 kg/m^3$.

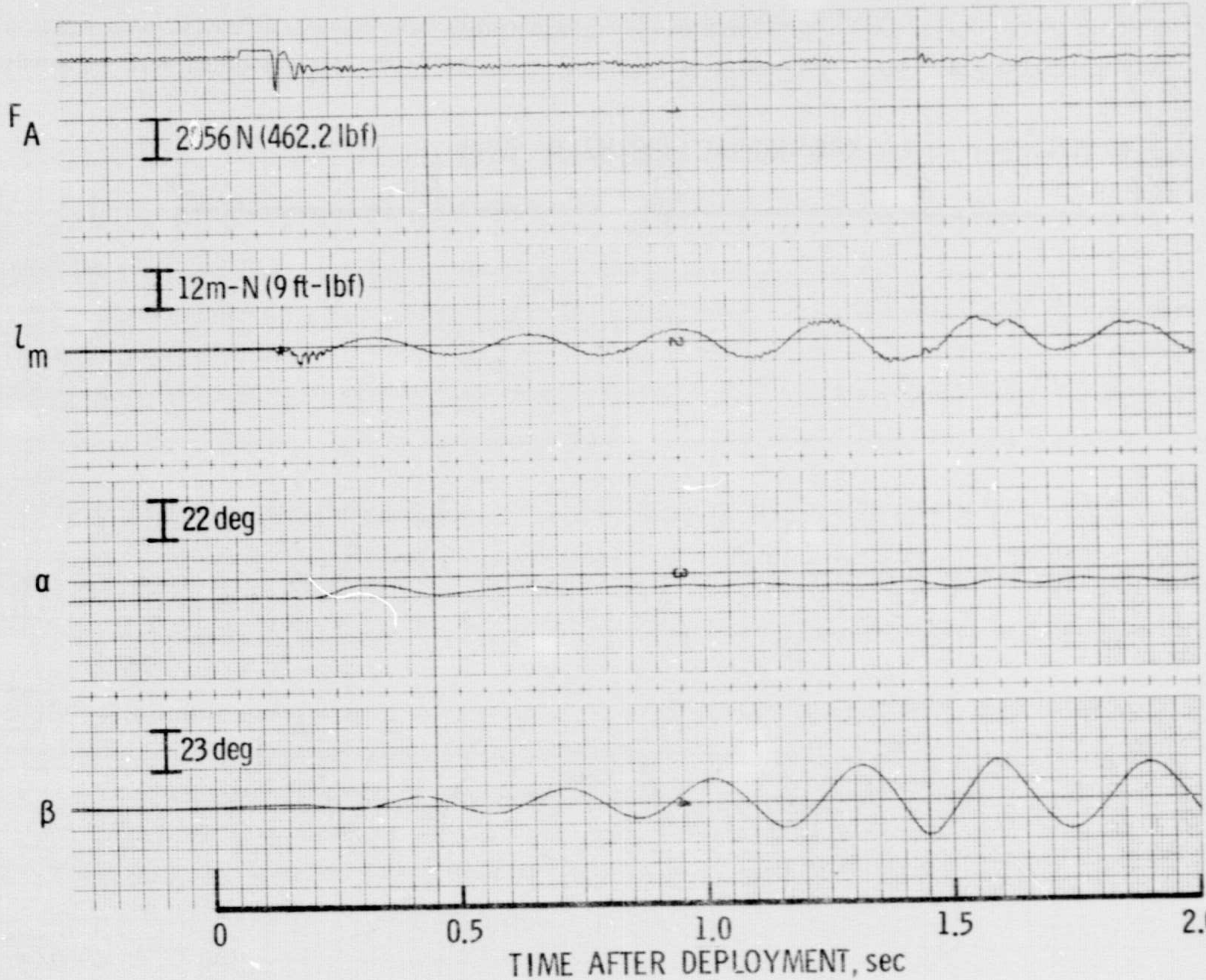

Figure 8.- Time histories for deployment to a parachute reefing ratio of $L_R/D_C = 0.41$, $M = 1.14$, $q = 4.79$ kPa (100 lbf/ft^2), $\rho = 0.0763$ kg/m^3.

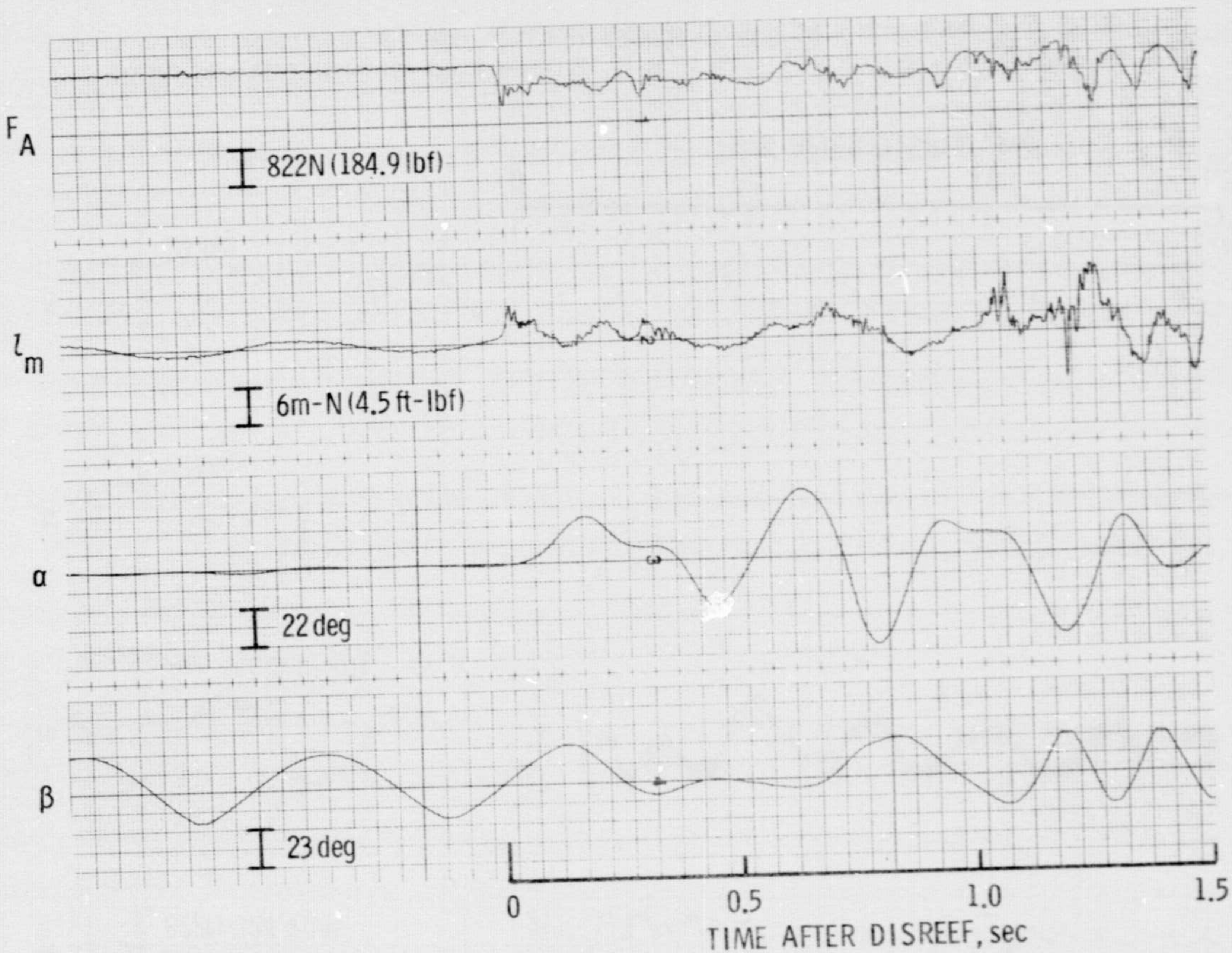

Figure 9.- Time histories for disreefing, $L_R/D_C = 0.41$, to a parachute full open condition. $M = 0.52$, $q = 1.48$ kPa (31 lbf/ft^2), $\rho = 0.0979$ kg/m^3.

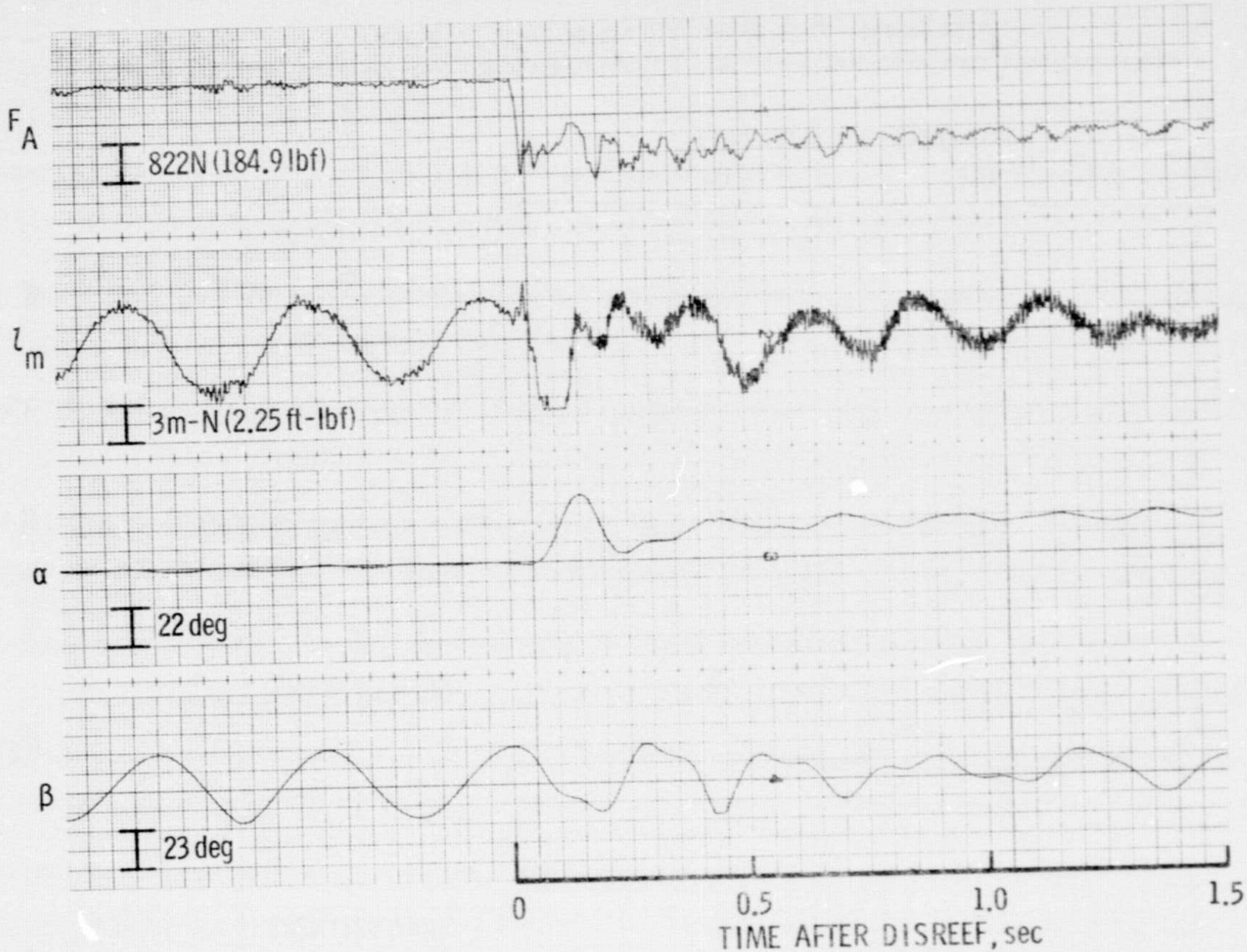

Figure 10.- Time histories for disreefing, L_R/D_C = 0.35, to a parachute full open condition $M = 0.92$, $q = 3.59$ kPa (75 lbf/ft^2), $\rho = 0.0799$ kg/m^3.